UNITED STATES MARINE CORPS
MARINE CORPS SYSTEMS COMMAND
2200 LESTER STREET
QUANTICO, VIRGINIA 22134-5010

IN REPLY REFER TO:
5720
DON-USMC-2015-000018
9 Nov 15

SENT VIA EMAIL TO: stesiwarski@gmail.com
Mr. Steven Siwarski
1423 SE 27th St.
Cape Coral, FL 33904

SUBJECT: FOIA DON-USMC-2015-000018

Dear Mr. Siwarski:

This responds to your FOIA requested dated October 1, 2015, which requests a copy of Lomasney, H., O'Niel, T. (2004), Innovative Camouflage. Technical report for Office of Naval Research under STTR agreement N00014-03-M-0344.

In light of the *MCI Worldcom, Inc, v. GSA* decision, the Department of Justice Office of Information and Privacy has advised the Navy Office of the General Counsel that submitter notification in accordance with Executive Order 12,600 should be made whenever an agency receives a FOIA request for documents that contain potentially confidential information in order to obtain and consider any objections to disclosure. Therefore, in accordance with Presidential Executive Order 12,600, we allowed the submitter to review the documents and provide comment.

Pursuant to the aforementioned Executive Order 12,600 request, the submitter provided the Marine Corps Systems Command with proposed redactions pursuant to Exemptions 5 U.S.C. § 552(b)(4). These submitter redactions are identified in the enclosed document.

Specifically, FOIA Exemption 5 U.S.C. § 552(b)(4) exempts from disclosure (i) voluntarily submitted commercial or financial information provided that the submitter does not “customarily” disclose the information to the public and provided that disclosure would be likely to interfere with the continued and full availability of the information to the government, or (ii) information likely to cause substantial harm to the competitive position of the person from whom it was obtained and likely to impact on the government’s ability to obtain reliable information in the future. See Critical Mass Energy Project v. NRC, 975 F2d 871, 879-80 (D.C. Cir. 1992), cert. denied, 113 S. Ct. 1579 (1993); National Parks & Conservation Ass’n v. Morton, 498 F2d 765, 766 (D.C. Cir. 1974); Canadian Commercial Corp. v. Dept. of Air Force, 514 F.3d 37 (D.C. Cir., 2008).

In an effort to minimize further delay we request that you review the enclosures and identify any withheld information that you believe was withheld improperly. MARCORSYSCOM will then determine whether the release of any requested information is proper under the FOIA and provide any additional releasable information in a “final release” letter. If we do not receive any notification from you, which specifically requests the release of any redacted information by November 30, 2015, this letter will become the final response and we will close this FOIA request.

As of November 9, 2015, one half hour of search and review (currently billed at $44 per hour) has been expended during the processing of your request. Please remit a check or money order, payable to the Treasurer of the United States in the amount of $22.00 to: COMMANDER, ATTN LAW, MARCORSYSCOM, 2200 LESTER STREET, SUITE 120, QUANTICO VA 22134-5010.

If at any time you are not satisfied that a diligent effort was made to process your request, you may file an administrative appeal with the Assistant to the General Counsel (FOIA) at: Department of the Navy, Office of the General Counsel, ATTN: FOIA Appeals Office, 1000 Navy Pentagon Room 4E635, Washington DC 20350-1000.

For consideration, the appeal must be received in that office within 60 days from the date of this letter. Attach a copy of this letter and a statement regarding why you believe an adequate search was not conducted. Both your appeal letter and the envelope should bear the notation "FREEDOM OF INFORMATION ACT APPEAL". Please provide a copy of any such appeal letter to the MARCORSYSCOM address above.

Any questions concerning this matter should be directed to Mrs. Bobbie Cave at (703) 432-3934 or bobbie.cave@usmc.mil.

Sincerely,

Bobbie Cave

for LISA L. BAKER
Counsel

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The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Navy position, policy or decision, unless so designated by other documentation.

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13. ABSTRACT (Maximum 200 words)

Report developed under STTR Contract.
The purpose of this Phase I STTR is to demonstrate the feasibility of a systematic program to adapt the MARPAT camouflage measure now used on the Marine Corps utility uniforms to a broader application for vehicles and shelters. The project combines systematic application of the MARPAT principles with an innovative strippable coating system that provides the capability to move from one scheme to another expeditiously without a decrease in survivability and while enhancing NBC decontamination capability.

The objectives achieved in this Phase I effort were:
1. Development of testing regime for evaluating visual detection characteristics
2. Demonstration of MARPAT design for EFV, HUMMVW and collective protection tents
3. Documentation of process for application of MARPAT pattern
4. Development of removable coating system which meets preliminary screening requirements
5. Demonstration of application and removal of MARPAT pattern on HUMMVW mockup using novel coating

Testing is underway as of the date of this report to demonstrate the NBC decontamination properties of the coating.

14. SUBJECT TERMS
SBIR Report, CARC, Nanoparticle, No VOC, Primer, Isocyanate, Self-decontaminating

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Acronyms

CARC	Chemical Agent Resistant Coating
CEES	Chloroethylethylsulfide (half-Mustard)
DS-2	Decontamination Solution #2
DTM	Direct to Metal
(b) (4) [redacted]	(b) (4) [redacted]
PVC	Pigment Volume Concentration
(b) (4) [redacted]	(b) (4) [redacted]
VOC	Volatile Organic Compound

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I. Executive Summary

The objective of this Phase One STTR was to demonstrate the integrated development of two emerging technologies to deliver an advanced Field-Applied Camouflage (FAC) system. One technology is based on vision science and the other on rapid deployment, strippable coatings technology. The objective of this integration was to demonstrate a means to significantly reduce the detectability, and hence the vulnerability, of Marine Corps vehicles and shelters, while simultaneously providing a weight conserving, "on-the-fly" ability to adapt the camouflage to the environment. This technology would also provide unprecedented operational flexibility and will lay a foundation for advanced Nuclear, Biological and Chemical (NBC) decontamination capabilities. The process will minimize the weight buildup associated with camouflage change.

The current visual camouflage measures used on Marine Corps vehicles and shelters reflect extraordinarily old technologies, most dating to the 1940's and before. The current vehicle pattern is a 3-color NATO standard measure introduced over 20 years ago that uses this old approach. Research from the mid-1970's and since, based on newer understanding of how the human visual mechanisms are marshaled to detect and recognize targets offers the probability of successful improvement in performance. Parallel developments in coatings technology offer similar improvements in flexibility over a range of climates and deployment areas.

Operational requirements of the U. S. Marine Corps require a combination of threat reduction and flexibility, since units may be deployed across a range of environments from woodland to high and low desert areas, with variations in camouflage requirements as seasons change. Limitations of current camouflage measures and application technologies combine to make such flexibility almost impossible to attain. This STTR has demonstrated a comprehensive and integrated solution to the challenges facing the Marine Corps' in this technology area by combining advanced camouflage capability with the ability to change camouflage characteristics rapidly and without adding weight when deployment needs change.

What has been demonstrated in these Phase I SBIR efforts has gone beyond just the demonstration of concept. Isotron and the United States Military Academy (USMA) have demonstrated the feasibility of two removable coating systems which meet initial screening tests based on EFV program requirements and select requirements outlined in the MIL-C-53039B CARC specification. In addition to this, the STTR team has developed pattern templates for the EFV, HUMMVW and collective protection tents. These templates were taken one step further to demonstrate actual application and removal of the pattern on the complex geometry of a HUMVW mock-up. The USMA has established testing protocols for evaluating the reduction in visual signature that is achieved using the MARPAT pattern. A pilot-scale test was carried out using this testing protocol and demonstrated as high as 50% reduction in signature using MARPAT versus the 3-color NATO pattern.

The following bullets summarize the achievements of these Phase I efforts which are described in detail of this Final Report:

1. Development of testing regime for evaluating visual detection characteristics
2. Demonstration of MARPAT design for EFV, HUMMVW and collective protection tents

3. Documentation of process for application of MARPAT pattern
4. Development of removable coating system which meets preliminary screening requirements
5. Demonstration of application and removal of MARPAT pattern on HUMMVW mockup using novel coating

It is important to note that Isotron has initiated live-chemical agent tests using HD and GD challenge agents in order to demonstrate the decontamination feature of the removable coatings. These tests are underway as of the writing of this final report. In addition to these achievements, the STTR team has provided insight into the cost effective manufacture and fielding of these coating candidates in the form of a Life-Cycle Cost Model which will be refined as the program advances.

II. Introduction

This Phase I STTR was organized to deliver an integrated technology which is based on two novel concepts. [redacted] (b) (4) The Isotron team investigated the benefits that result from [redacted] (b) (4) These were formulated [redacted] which achieved the low spectral gloss and barrier properties at relatively low pigment loading (below critical Pigment Volume Concentration – cPVC). Note that the Phase I investigation also provided a "demonstration of concept" of the potential of [redacted] (b) (4) which would be explored in a future phase of the program as the means to deliver a self-decontamination feature.
The pattern efficacy measurement that is sought in this solicitation – and the one that is to be used in the activity that is proposed by this ISOTRON team – is unique in several ways from other measures that have been used in or considered for military application over the last century. It is similar to the current MARPAT measure, but has been improved and modified for use on vehicles and other equipment.

The Advanced MARPAT disrupts the detection and recognition processes by use of two simultaneous pattern elements, called the micropattern and the macropattern. The micropattern is crafted to match as closely as possible the texture of the tactical environment in which the equipment will operate, while the macropattern disrupts the target shape in ways that retard recognition once the target has been detected. These tasks are governed to an extent by distinct visual pathways and mechanisms, and different pattern mechanisms are required to affect each.

The Phase I effort demonstrated the efficiency of the advanced MARPAT concept (which is compatible with ADCAM) as compared with other possible camouflage techniques as it relates to the application method [redacted] (b) (4) and the feasibility of rapid field deployment. This application process will be designed such that can easily be incorporated into the training of the vehicle crewmen or troops (as opposed to a specialty MOS).

Critical to the design of the removable MARPAT coating system are the parameters of durability and strippability (or release). The strippable coating will be designed for application over the CARC. Isotron's models of release mechanisms and experience derived from large scale application of strippable coatings in the nuclear industry conclude that one of the principle mechanisms [redacted] (b) (4)

Traditionally, elastomeric strippable coatings have been applied in decontamination scenarios or in environments where durability requirements are driven by foot traffic and lightweight equipment traffic over the coated surface. This is not the case for the proposed application where a high level of coating durability will be required to render the system effective in harsh battlefield and immersion service. Isotron has worked extensively within the nuclear industry to design strippable coating systems that will withstand high-temperature immersion environments (such as those encountered in the nuclear reactor core – See Reference 4). For the proposed application, the strippable coating system will incorporate this immersible property with a highly durable coating system [redacted] (b) (4)

(b) (4)

The novel Field Applied Camouflage (FAC) strippable coating system involves [redacted] (b) (4)

The goal of this element of the proposal is to demonstrate a polymer composition that meets the military's requirement for a strippable coating, suitable for integration with the advanced MARPAT camouflage measure, including application methodology and field removal techniques.

Another key feature of the coatings developed in this Phase I effort is the reduced toxicity of the coating. This will have positive impact on "change-of-theatre" painting operations and logistics. The problems associated with current generation CARC systems are two-fold. The first is associated with the environmental impact of VOC solvents that are used in these coatings and which contribute directly to SMOG formation. As a result, the U.S. Military is taking an aggressive position to reduce the VOC content in its specified coatings.

The second problem associated with current CARC coatings is related to the health impact on coating applicators. During Desert Storm, the United States military sent thousands of vehicles and equipment to theater which needed repainting to change from the woodland green to the desert camouflage scheme. The military established painting operations in Saudi Arabia. In current generations of CARC, isocyanates and VOC solvents are used in order to achieve the chemical resistance feature as well as the toughness and durability service requirements. Isocyanates are known to cause serious problems in the respiratory system and are harsh skin and mucous membrane sensitizers[1]. The Gulf War painting operations were reportedly limited in personal protection equipment, and it was later discovered that there was inadequate adherence to applicable safety and occupational health policies and procedures[2]. Even still, some infantry units were required to re-paint their own vehicles forward of these sites with relatively no protection at all. The materials used were hazardous to those in the process, as the current CARC can be toxic before it fully dries. Isotron has developed and demonstrated a coating which contains no isocyanates and which is primarily waterborne and can be effectively used in such "change of theatre" operations.

Finally, Isotron has demonstrated a coating which enables the decontamination of a vehicle [redacted] (b) (4)

[1] United States Naval Flight Surgeon's Manual: Third Edition 1991: Chapter 21: Toxicology: Isocyanate
[2] Environmental Exposure Report: Chemical Agent Resistant Coating, July 27, 2000 (http://www.gulflink.osd.mil/carc_paint_ii/)

III. Background

Current USMC CARC topcoat and primer systems are required to protect aluminum, steel and organic matrix composite substrates from the harsh natural and service-imposed operational environments, minimize enemy threat detection, and resist contamination/degradation by chemical agents. High performance topcoats for these applications have historically been based on two component solvent-based urethane topcoats and more recently on single component solvent-borne and dual component water-dispersible urethane topcoats which achieve full-cure properties at room temperature within 7 days. These types of paints currently have Volatile Organic Compound (VOC) levels of 210 - 420 g/l. Although these topcoat technologies produce materials of satisfactory performance, component mixing and concentration errors have occurred in the field with multi-component paints with less than acceptable results. The primers, individually and as part of the chemical agent resistant coating (CARC) system, must resist contamination/degradation by chemical agents as well. Good coating cohesive strength and good adhesion at the substrate/primer and primer/topcoat interfaces are essential since both the primer and the topcoat afford specific and essential functionality to the overall performance of state-of-the-art CARC systems.

In current generations of CARC, in addition to VOC solvents, chemicals known as isocyanates are used in order to achieve the chemical resistance feature as well as the toughness and durability service requirements. However, isocyanates are known to cause problems in the respiratory system and are harsh skin and mucous membrane sensitizers[3]. There is a cause for alarm in the adverse health effects relating to exposure to hexamethylene diisocyanate (HDI) and other VOCs associated with the traditional CARC coatings. The primary health concerns associated with the CARC involves the inhalation of airborne droplets containing HDI, released during spray application. Systemic effect studies have determined that inhalation exposure can cause asthma, shortness of breath and other respiratory distress effects[4]. It is for this reason that the safe handling of isocyanate materials requires that the persons exposed to these vapors be protected with air supplied respirators, and protective suits that assure that the uncured coating cannot be inhaled or contact the skin. However, this was hardly practical in the expeditionary role where the Theater of Operation could change in the course of a few days.

This Phase I SBIR effort has achieved the design of three coating candidates, two topcoats and one primer, which are all single pack, contain ultra-low to zero VOC and have no free isocyanates. These objectives have been achieved in coating candidates which meet a Coating Qualification Test regime which is based on the MIL-C-53039B (topcoat) and/or MIL-P-53030 (primer) requirements specification.

[3] United States Naval Flight Surgeon's Manual: Third Edition 1991: Chapter 21: Toxicology: Isocyanate
[4] International Consensus Report on: Isocyanates – Risk assessment and management (http://www.arbeidstilsynet.no/publikasjoner/rapporter/pdf/rapport1c.pdf)

IV. Phase I Innovations - COATING

The phase I objective of this SBIR, provided that Isotron identify resin and pigment candidates that will deliver a next generation of chemical warfare agent (CWA) resistant CARC coating that combines enhanced performance with an environmentally responsible material composition. Isotron's approach to the primer and topcoat formulations adds to this the reduction of toxicity concerns associated with application, and the limitations imposed by curing of the coating under field application conditions. The compositions must cure quickly even under adverse weather conditions, to achieve a durable, protective coating. In delivering this next generation approach to CARC coatings, [redacted]

(b) (4)

A. Chemical Agent Resistant Polymer Design Concepts

(b) (4)

[redacted]

(b) (4)

[redacted]

B. [redacted]

(b) (4)

(b) (4)

[redacted]

(b) (4) [redacted]

(b) (4) [redacted]

(b) (4) [redacted]

Figure 1 (b) (4) [redacted]

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Figure 2. (b) (4) [redacted]

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(b) (4)

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Figure 3. (b) (4) [redacted]

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C. (b) (4) [redacted]

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(b) (4)

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(b) (4)

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Figure 4. [redacted] (b) (4)

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Figure 5. [redacted] (b) (4)

(b) (4)

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D. [redacted] (b) (4)

(b) (4)

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(b) (4)

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(b) (4)

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Figure 6. (b) (4) [redacted]

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(b) (4)

[redacted]

(b) (4)

[redacted]

(b) (4)

[redacted]

The improved MARPAT design used for demonstration purposes in Phase I of this program is derived from the original Dual-Texture measure (O'Neill et al., 1977a, 1988a; CDEC, 1979), with the addition of a macropattern feature. It resembles the MARPAT clothing pattern, but combines that pattern with a macropattern impractical for a uniform and uses a coarser pixel component appropriate to detection at longer ranges.

1. Macropattern design

The macropattern is derived from an analysis of the symmetry axes of the target (EFV below – red lines). This internal stick figure is described by Blum (1968, 1973), Psotka (1978), and O'Neill et al. (1982;1986a), and is related to visual processes used in recognizing a shape. The macropattern design (green dashed lines) is so constructed as to cross or disrupt the symmetry axis lines. Concealment patterns of this kind are seen in animal patterns (Murray, 1988) and have been applied successfully to military vehicle concealment (O'Neill et al., 1986a). The macropattern degrades the observer's ability to recognize the shape of a target.

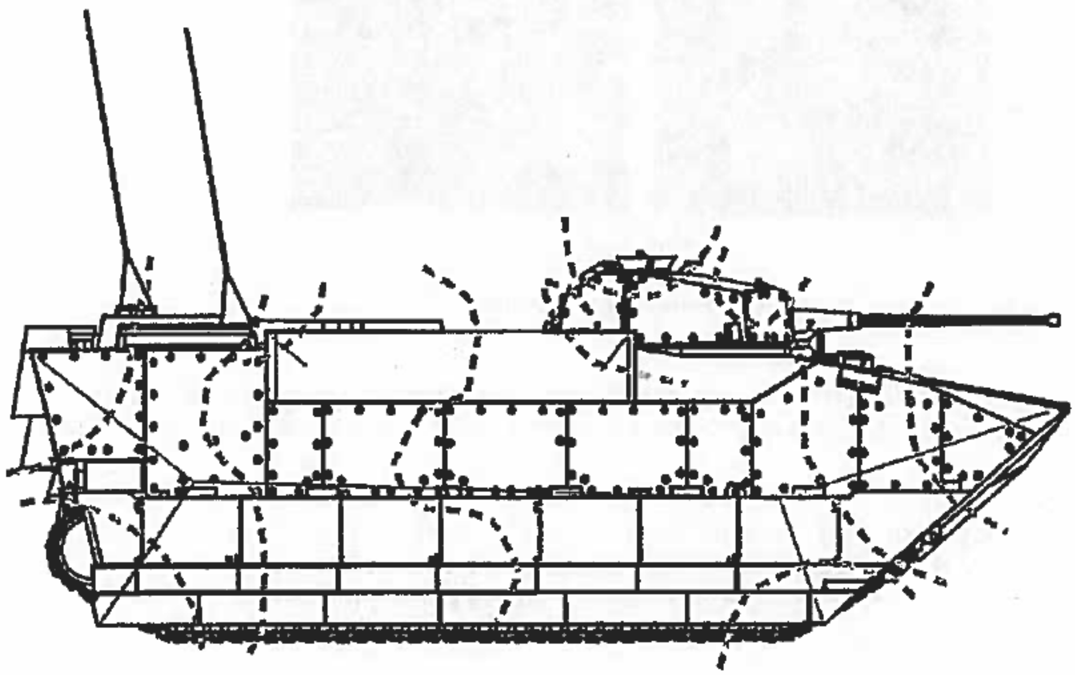


Figure 1: EFV macropattern generation The Blum symmetry axis (red lines) suggests a disruptive series of macropattern elements (suggested by the broken green lines) that break up the internal symmetries of the target and visual affect recognition.

2. Micropattern design

Once the general configuration of the macropattern is determined, the overall patches of contrasting pattern elements are established. These light and dark areas are then decomposed (or "quantized") into small pattern elements or pixels. The size of the pixels is determined by survey of the likely deployment areas, which yields a basic texture unit or "optel" that will be matched by the size and configuration of the pattern pixels.

The critical pattern quality here is what we may conveniently call *texture*. Texture is the size and arrangement of the visual elements from largest that can be discriminated at range to the larger configurations. The largest pattern elements are represented by the collective macropattern; the smallest elements are the pixels. In the example used in this report, we have specified a pixel size of about 4 inches square; this may change in later phases as we have an opportunity to perform a closer survey of target environments.

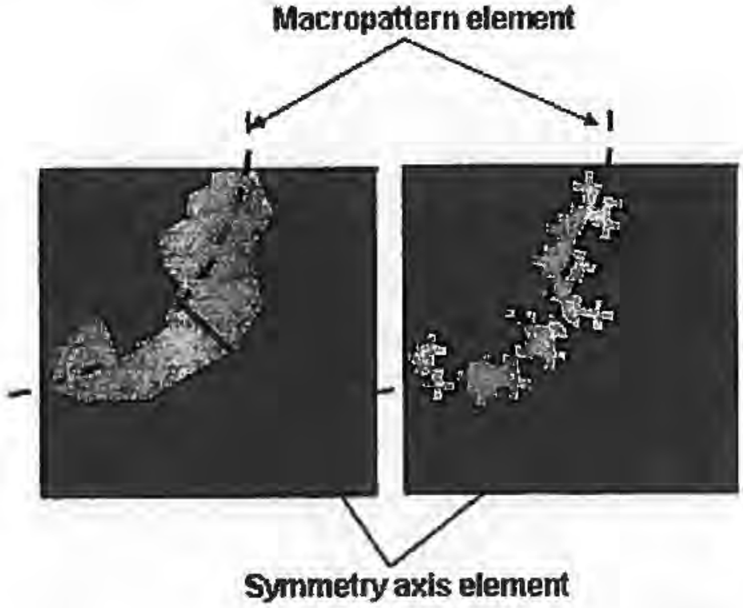


Figure 2: Macropattern to micropattern. The macropattern element disrupting the symmetry axis "primitive" (light green patch over solid red line) on the left is decomposed into pixels (right) matching the texture of the natural background.

In the more advanced phases, the texture of the micropattern will be derived from photographs of selected deployment areas; these photos will be digitized and analyzed for texture (using a mathematical procedure called a "two-dimensional Fourier analysis") and the size of the pixels and pixel clusters appropriately matched.

3. Color palettes

Exact colors to be used in the coatings cannot be fully specified until site surveys have been completed. It is likely that the current MILSPEC palettes will in most of all cases suffice to match backgrounds.

4. Application of the pattern

The technical process for applying the pattern over the strippable coating is described in detail elsewhere in this report. [redacted]

(b) (4)

(b) (4)

[redacted]

5. Examples

We have provided three example patterns: For the EFV, for the HUMMV, and for a typical large shelter tent. The principles are the same for all likely targets to be concealed (though fabric items such as tents will not use the strippable coating – only the pattern).

These patterns use notional colors to demonstrate roughly how they would appear when applied. The colors have been shown in a transparent form to allow the details of the target (which will be used to position stencils) to show through. Poster-size copies of these figures have been provided.

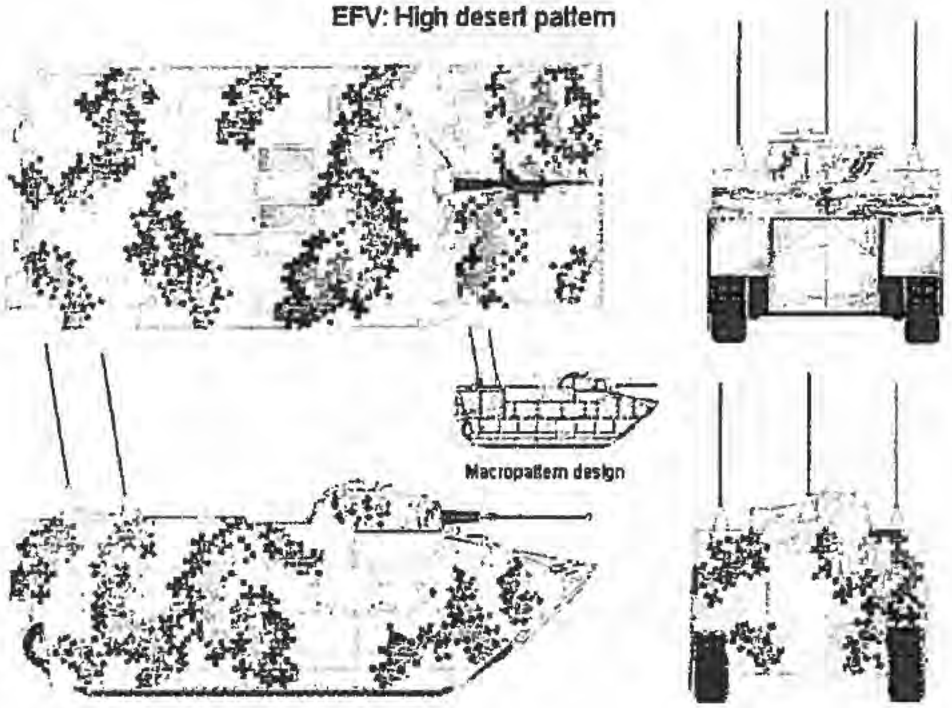


Figure 3: EFV, high desert pattern (notional)

Figure 4: EFV, Woodland pattern (notional). Hardwood and softwood forest have somewhat different color palette specifications. Softwood (evergreen) forests have a somewhat bluer green hue, against which forest greens designed for and matched to hardwood (deciduous) forest appear yellowed.

HUMMWV High Desert

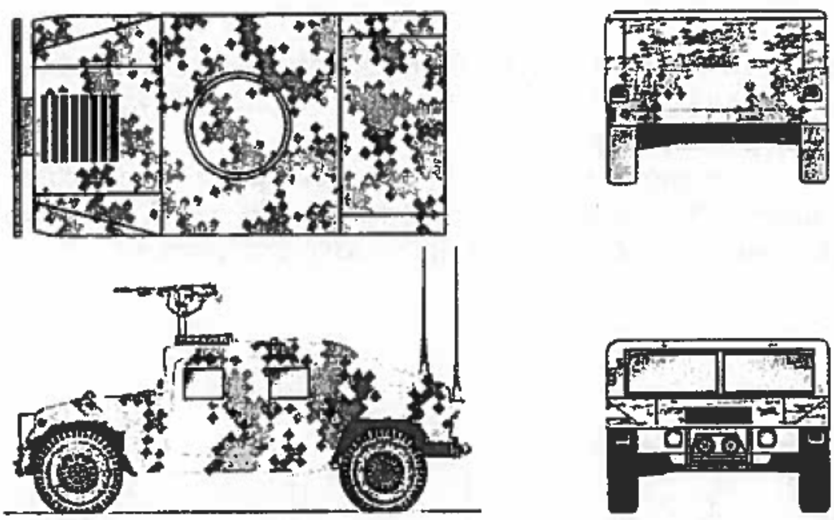


Figure 5: HUMMWV (high desert pattern)

HUMMWV Woodland

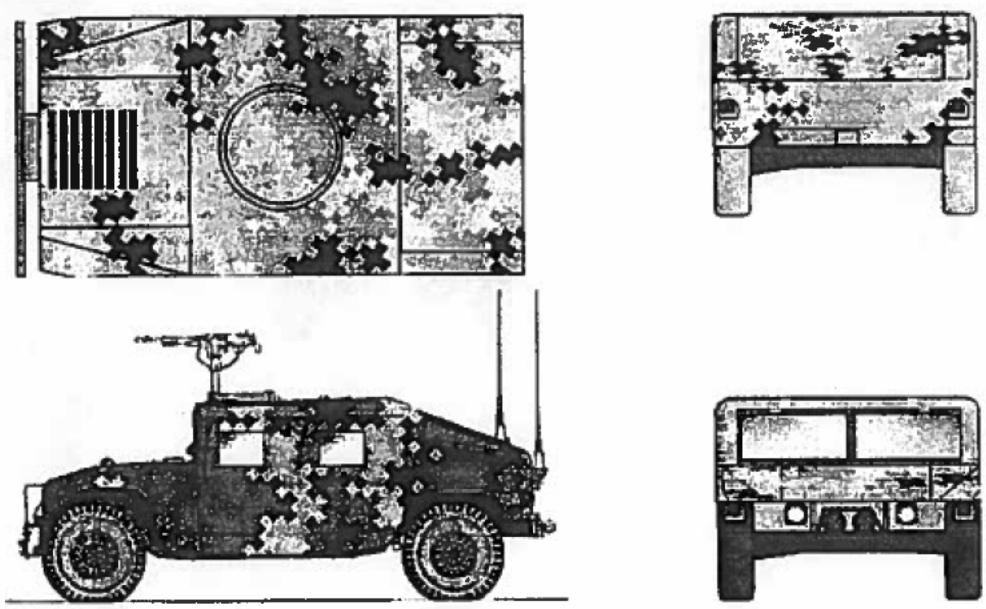


Figure 6: HUMMWV Woodland Pattern

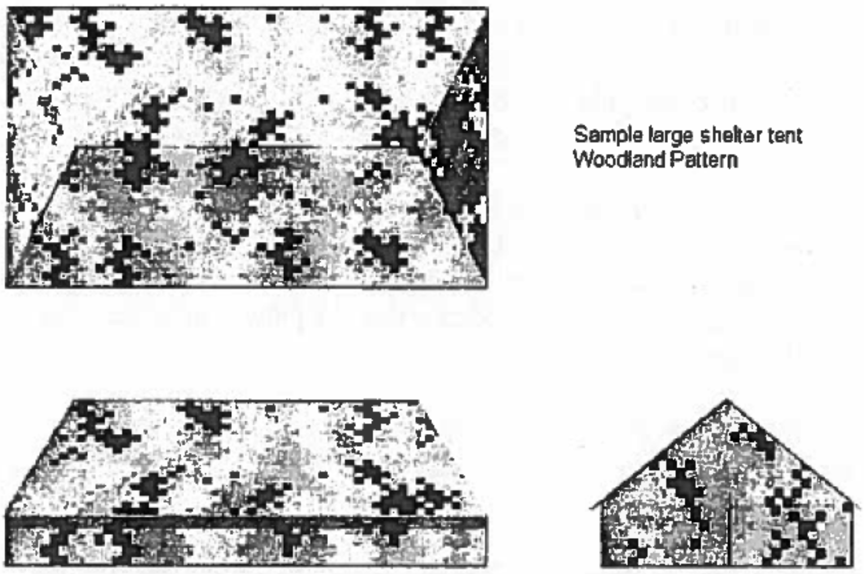


Figure 7: Type shelter pattern. (Pixel coarseness is exaggerated to show major pattern elements). Smaller shelters are simply printed with existing MARPAT measure.

Pilot test

As preparation for Phase II test requirements (detectability evaluation), the team conducted pilot testing at the United States Military Academy in October 2003. The objective of this effort was to identify the most appropriate methods and protocols to be used in determining the influence of the improved MARPAT measure on survivability, as well as verifying the likelihood of successful demonstration.

As documented in the initial STTR proposal, the basic MARPAT design was demonstrated in the 1970's and 1980's (O'Neill et al., 1977a, 1978; CDEC, 1979; O'Neill et al., 1986a). Since the initial research and development phases several theoretical improvements have been added (macropattern design, optel analysis). We began with high confidence that the pattern measure would compare favorably with existing alternatives.

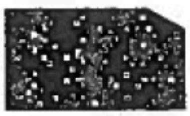
General: The STTR requirement specified a photosimulation method, which we generally consider the most effective first step in test and evaluation of camouflage measures despite some past misuse.

Observers: This pilot test employed 48 US Military Academy cadets who participated in the study as a requirement for the general psychology core course. Observers were male and female; all had at least 20/20 Snellen acuity (some wore corrective lenses); all were given the Vision Contrast Test System (VCTS) evaluation[5] as well. All West Point cadets have normal color vision.

Stimuli: We employed a large series of digital photographs of natural backgrounds (fields and hardwood forest near Culpeper, Virginia) into which targets were placed in various locations. We used three test stimuli: (1) the improved MARPAT; (2) an adaptation of the current 3-color NATO pattern; and (3) a monocolor green target for comparison. The color attributes were adjusted in each case so that the same general color scheme was used in all targets, with adjustment to assure that the overall brightness did not vary). Only brightness was adjusted – the other color attributes (hue and saturation) were the same. The monocolor targets were in the dark green hue common to all examples, but lightened slightly to assure that overall brightness (and hence contrast with the background) were the same.

[This measure may seem fussy, but experience has shown that this variable can invalidate tests of this kind. We must remember that what is being tested here is not the paint color or the overall brightness, but the effectiveness of the pattern configuration; if we do not control for color and brightness, the method will violate the requirements of internal validity.]

Procedure I (detection time): First, Observers were briefed on the requirements for the experiment and pretested (VCTS). Observers were seated in front of computer displays and given verbal instructions supplemented by on-screen step by step procedures and ten practice trials.



[5] The VCTS evaluates spatial vision, recording the spatial frequency modulation transfer function for each Observer. O'Neill et al. (1988) demonstrated a strong correlation between MTS and target detection, and this score was intended to be a covariate in the multivariate general linear model.

Figure 8: Target slides used in pilot test; left-right, NATO 3-color, monocolor, MARPAT. Note "chopped" corners used for recognition subtest. Targets as displayed subtended a retinal angle of approximately 2 degrees at a viewing distance of 18 inches.

There followed a series of some 80 slides showing natural backgrounds into which targets had been inserted. The backgrounds varied, but there were more trials than backgrounds; hence each background appeared a number of times. Each target appeared against each background in three positions – left, right, and center – to compensate for the possibility that some positions might be more likely to hide the target whatever its pattern. Here is a typical slide:

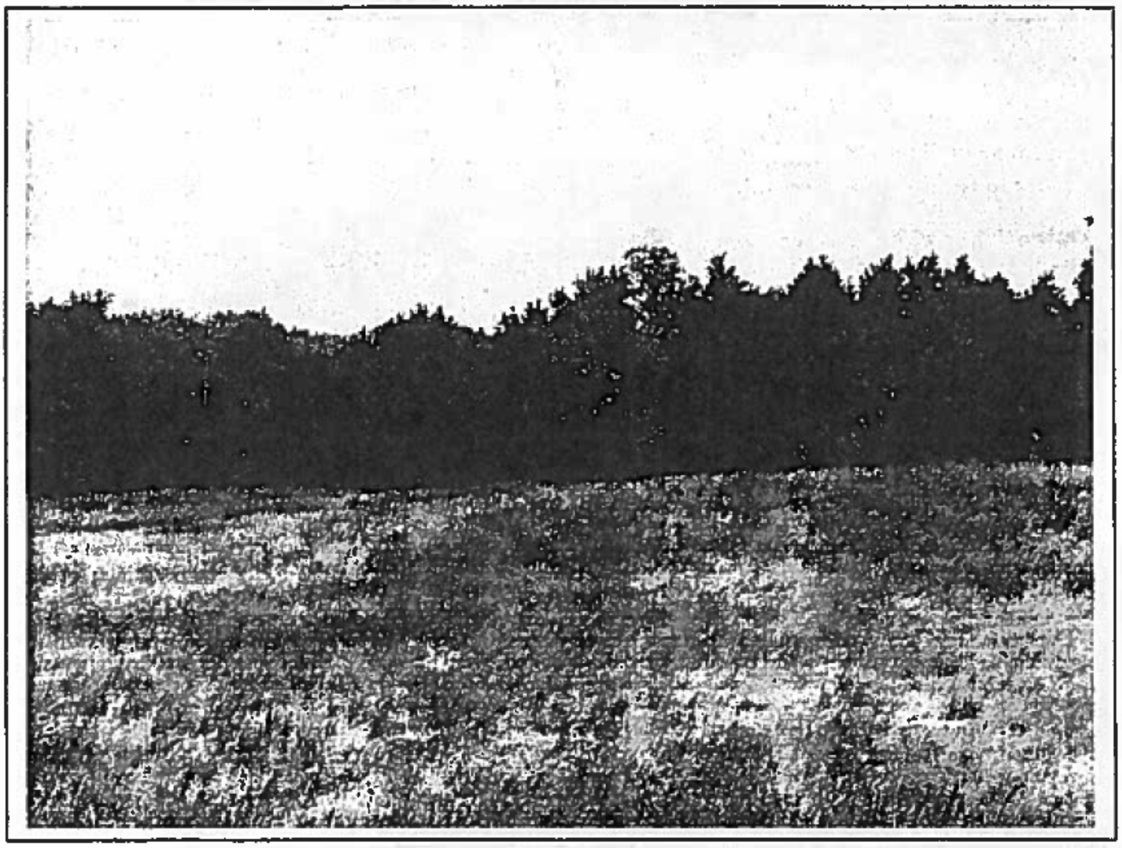


Figure 9: Test slide example 1. In this case, the target is the monocolor control panel with the chamfered edge in the upper left, in the center of the tree line.

In each presentation, the Observer began by placing his gaze on a center cross against a neutral background. On pressing a key, this view was replaced by an image like the one above. The Observer searched the field until detecting the target, at which time he

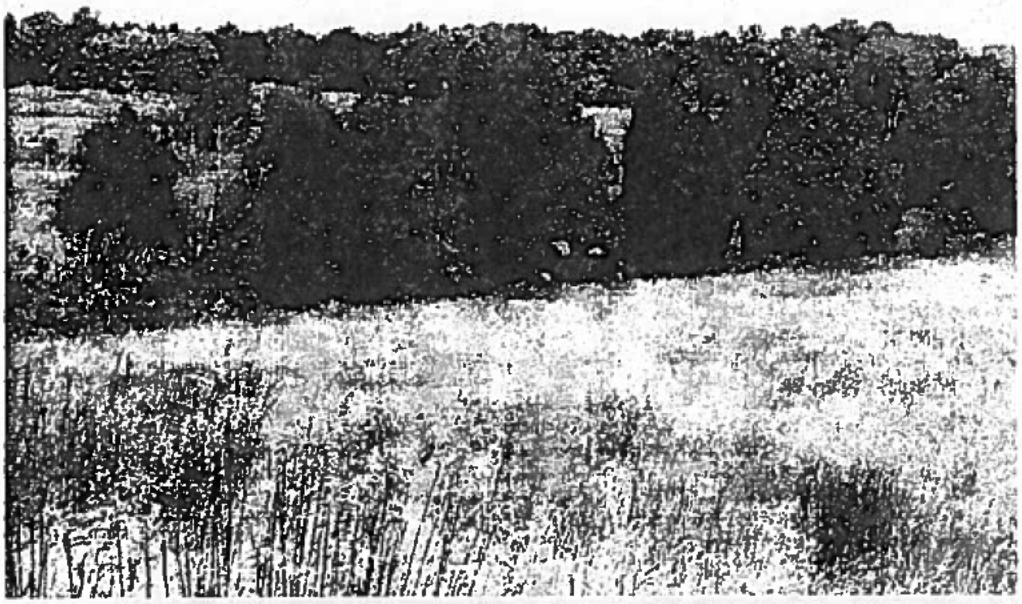


Figure 10: NATO pattern (center of tree line)

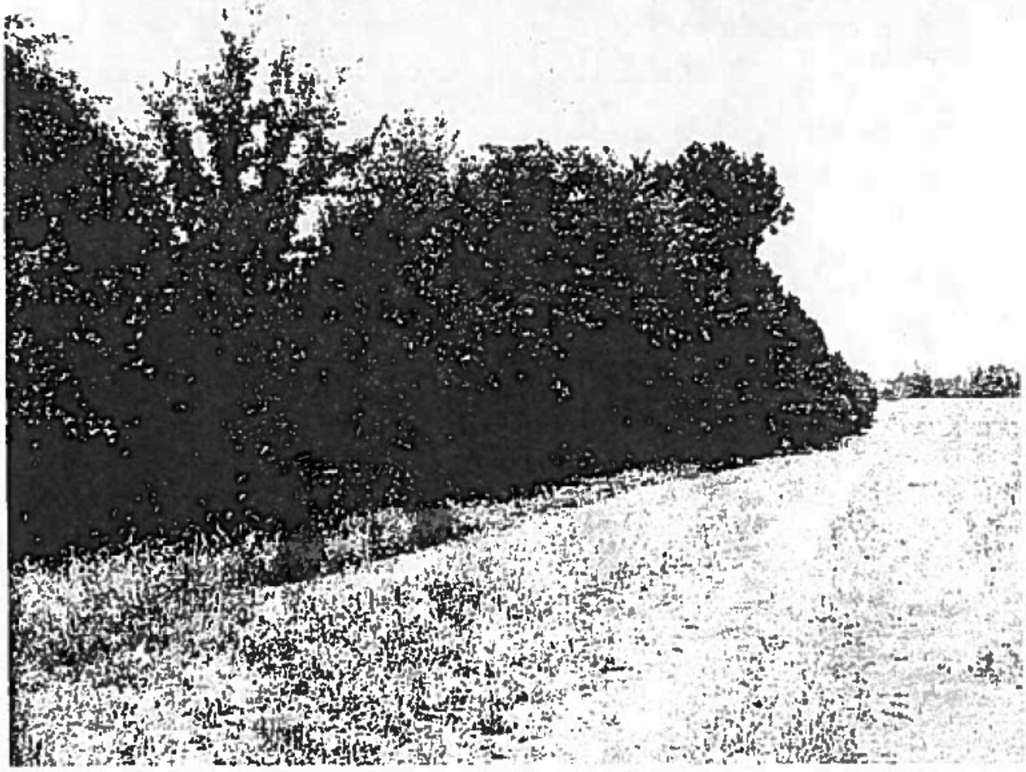


Figure 11: MARPAT target (upper left – arrow)

signaled detection by pressing a key a second time. Then he was to inspect the target until he could identify the corner that was cut off at an angle (this task being a measure of recognition as opposed to detection), at which time he pressed the key again. At this time the field reverted to the gray background and fixation cross, and the next trial began. The computer program recorded the time in milliseconds required for detection and then recognition.

The test design was balanced to assure that every target appeared in each position against all backgrounds.

A second test was also employed using, instead of detection time, probability of a detection. This is called a signal detection task, and generally results in a ratio of correct detections ("hits") to incorrect detections ("false alarms"). To measure this attribute, a series of 80 slides was presented to the Observers, each slide being a natural wooded background filling the entire screen. In three quarters of the slides there was a target embedded; in the remaining quarter there was no target. The slides were presented for 250 milliseconds each, with targets (where present) positioned in any of twenty positions arranged in a systematic array:

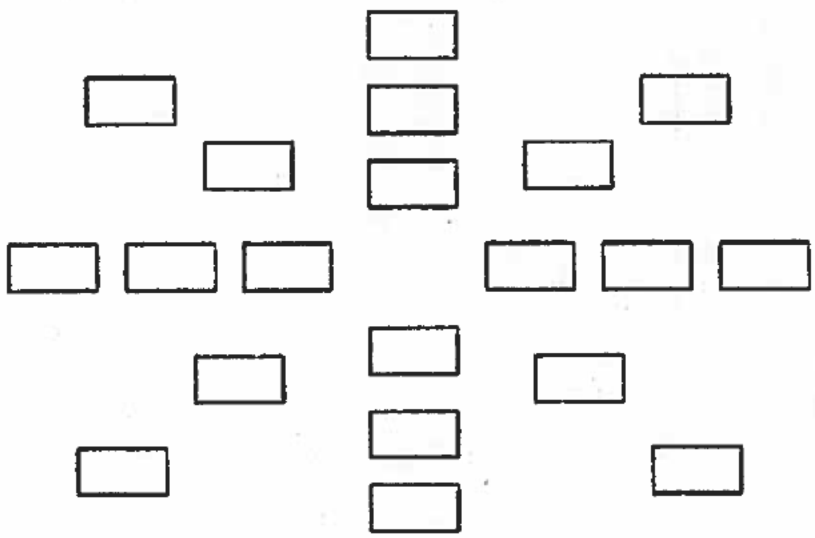


Figure 12: Target positions, signal detection test

The same patterns were used, and were so arranged that each pattern type appeared in the same positions as others, removing location effect. This resulted in a series of 80 slides.

The method was somewhat more complex than that used in the simple detection time experiment. Observers viewed the brief presentation and signaled presence or absence of a target using specified keys on the computer keyboard; then, as a check against guessing, indicated the general location of the target using the numeric keypad. This approach proved to introduce errors in keying, in particular reducing the accuracy of the "false alarm" statistic.

Results

Detection time: The pattern effect demonstrated in the first experiment was exceptionally powerful. With respect to the time required to locate a valid target, the results matched the theoretical prediction: the improved MARPAT was by far the most difficult to detect, requiring more than three times as long as the monocolor control target and more than twice as long as the NATO pattern. We note that this is a stronger result than was discovered with the older Dual-Texture pattern in the 1970's-80's.

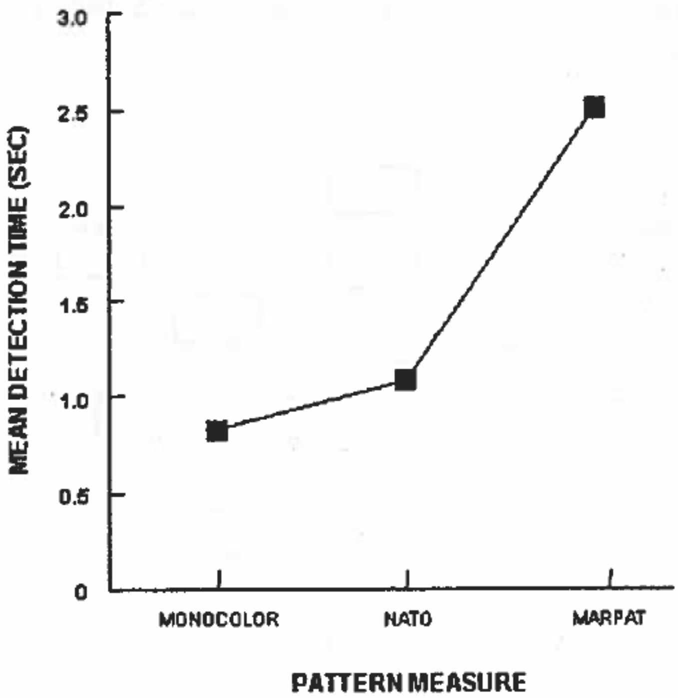


Figure 13: Mean time to detect a target by pattern

Analysis: The original analytical plan called for a mixed general linear model with VCTS result as a covariate (since this visual attribute has been shown to correlate highly with detection skill; O'Neill et. al., 1988). However, such a model depends on certain assumptions being met, the most important being "homogeneity of variance." The distribution of detection times for the MARPAT included a number of outlying scores (some targets were extremely difficult to detect) that increased the variance ratios above the minimum level (Keppel) for a parametric test. For this reason, we used the comparable nonparametric test (for which homogeneity of variance is not material), the Wilcoxon.

Since there is a clear theoretical prediction of detection time (monocolor>NATO> MARPAT), we used simple pairwise comparison (that is, for each attribute we compared monocolor and NATO, NATO and MARPAT, and monocolor and MARPAT).

All pairwise comparisons were highly significant ($p < .0001$).[6]

Recognition time: Once having found the target and triggered the timer, the Observer then inspected the target and "identified" it by determining whether the diagonal cut in the shape appeared in the upper right, lower right, upper left, or lower left. This is principally a measurement of the theoretical effect of the macropattern in making the shape harder to recognize. The results here are similarly supportive of the expected times:

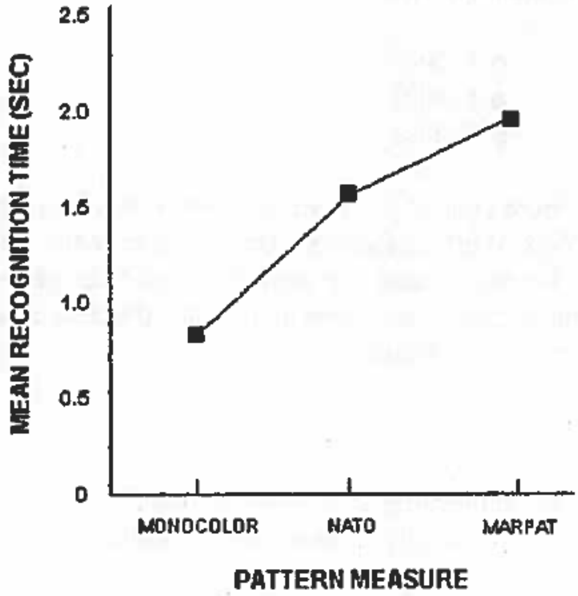


Figure 14: Mean recognition time by pattern

This result was somewhat muddled by the complexity of the task required of the Observers. It was noted during trials that many of the cadets appeared to lump detection

[6] For reviewers unfamiliar with this idea, "statistical significance" is not the same as practical significance. The measure of statistical significance is the probability that the observed differences occurred by chance. Such a probability is stated as "p < some value." The statement "p < .0001" indicates that the differences in detection time would occur by coincidence only once in ten thousand repetitions of this experiment. A p-value of .05 or lower is considered significant enough to report. However, for tests such as this, the best measure is the "test of interocular trauma" – if the graphed results hit you between the eyes, they are probably significant. We always run the statistical test in any case.

and recognition together instead of pressing the "detect" key as soon as the target was found. However, both effects were so powerful that the pattern order came through without difficulty. The MARPAT was not only more difficult to find, but also more difficult to recognize once detected.

Analysis: Again, outliers prevented use of a parametric test, and instead the Wilcoxon method had to serve. In this case, all pairwise comparisons were significant:

Monocolor – NATO	$p < .0001$
Monocolor – MARPAT	$p < .0001$
NATO – MARPAT	$p < .05$

In addition, shape identification was less accurate (in terms of percent correct) for the MARPAT than for the other patterns – that is, Observers were more likely to misidentify the shape for the MARPAT. Pairwise comparisons were all significant (paired t-test):

Monocolor – NATO	$p = .0087$
Monocolor – MARPAT	$p < .0001$
NATO – MARPAT	$p < .0001$

Signal detection: This experiment created problems for Observers. It appears that some incorrectly applied the "target – no target" click of left or right mouse button, in many cases incorrectly recording an observation of "no stimulus." For this reason, we could only examine percentage of "hits" and ignore "false alarms", a shortcoming that complicates and dilutes the desired analysis. We will correct this problem in the Phase II formal demonstration.

Discussion

This was intended as a pilot test to investigate the most productive method to be used in Phase II, not as a definitive demonstration of effectiveness. However, the nature and magnitude of the results deserve some discussion.

Validity questions: First, although the early research that led to the current improved MARPAT suggested a practical advantage over alternative measures (O'Neill et al., 1977a, c; 1986a), the current results show a notably greater magnitude. This should be viewed in light of two important factors.

The older Dual-Texture measure employed only the micropattern feature, the macropattern concept having been added much later based on an examination of the Blum symmetry axis geometry and its influence on shape perception. Since no other significant change has been made to the older patter, we speculate that the predicted combinatory effect of the two pattern elements has in fact appeared.

In addition, we note that the problems encountered with complex instructions are likely to have biased the results in a conservative direction – that is, the actual difference in detection time may be larger than it appeared in this preliminary test.

It is also important to understand a factor not always well understood in programs of this sort: the relationship between *internal validity* and *external validity.*

Internal validity is a measure of how sound the experimental method is in the sense of isolating the desired dependent variable – that is, "are we measuring what we think we're measuring?" This is why, for example, the fussy adjustment of color and brightness was so important; it assures us that the difference in detectability we see is due to the pattern configuration and not to some other variable such as hue or relative contrast with the background. It is for this reason – experimental control – that we are advised to begin in a laboratory setting. If the pattern effect does not appear in a controlled lab procedure, it will certainly not do so in the field.

External validity is the measure of generalization that asks whether the pattern makes a practical difference – in this case, in combat. It is very possible to find a statistically significant difference in the laboratory for an effect so weak that it disappears when we go to the field to validate its effectiveness.

In general, we take two factors into consideration:

- A field environment, unlike the laboratory, has very few controls on extraneous variables – in this case, such things as illumination (direct or diffuse sunlight; gloss; shadows; atmospheric interference) and specific siting of targets. Laboratory results generally have to be fairly dramatic if they are to translate into a practical combat advantage.

- Most important, we should remember that without internal validity, external validity is meaningless. We must be certain that the effect observed under controlled conditions is the effect we intend to test. This is why we are well advised not to go immediately into a field test setting.

The results of the pilot test are extremely encouraging; this is the degree of improvement we hope to find in the lab to assure an effect under combat conditions.

Test stimuli: There is generally a concern in detectability testing about the distance, or apparent distance, from the Observer to the target. The presumption is made that the effect on detectability should be demonstrable at a battlefield distance with unaided vision.

For example, a vehicle 5 m in length at a range of 1500 m will subtend about 11 minutes of arc. The stimuli used in this study were larger, approximately 2 degrees (or 120 minutes) long axis dimension. This raises commonsense questions of validity.

However, it is unlikely that a vehicle properly positioned at 1500 m will be readily detectable to the unaided observer; if it is visible at so great a range, it is probably because of a poor choice of position that reveals some reflection or other feature that creates an obvious signature.

In any case, use of photo slides or digitized images makes such a strategy unsuitable. A target image so small would be very difficult to see in a photograph, which is always of lower resolution than the visual system at optimal level of function. In addition, the pixels of a digitized image (or the emulsion of a photographic one) would be so coarse with respect to the size of pattern elements that the image attributes would mask the pattern configuration. (This is not an idle speculation; a major photosimulation that resulted in the selection of the current 3-color NATO pattern was rendered invalid by this very problem, though it was several years before the problem came to light.)

For this reason, we simulate a search for a target using optical magnification. We will adjust the size of the target images to represent the user's best estimate of a realistic combat situation.

In addition, the targets used in the pilot test were neutral rectangles that differed only in the corner that had been chopped. It may be more effective in the Phase II test to use vehicle silhouettes for identification.

V. Results and Discussion

The results of this Phase I SBIR are qualitatively and quantitatively recorded and analyzed by means of three evaluation regimes. The first testing regime is the Polymer Evaluation Protocol, which supported the rapid screening and initial optimization of polymer candidate systems. The second test regime, and by far the most comprehensive test regime of the Phase I effort, is the Phase I Qualification Program which considers the spectral, physical, weathering and chemical resistance properties of the pigmented and formulated coating candidates. The final evaluation regime is the Life Cycle Cost model which identifies the critical parameters that determine the overall economic advantages of the candidate coating systems.

A. [redacted] (b) (4)

In order to rapidly screen polymer candidates, Isotron's scientists developed a screening protocol that supported the initial down-select of polymer candidates and later supported optimization of the in-house synthesized polymer systems. Table 1 outlines the polymers that were evaluated during the Phase I polymer screening program.

Table 1. Polymers Evaluated in Phase I

(b) (4)
[redacted]

The screening protocol involved evaluation of solvent resistance (via MEK and $MeCl_2$ rubs), DS-2 resistance screening, flexibility and adhesion screening and evaluation of shelf-life and pot-life features.

(b) (4)

[redacted]

(b) (4)

[redacted]

Figure 7. [redacted] (b) (4)

(b) (4)

[redacted]

Figure 8 [redacted] (b) (4)

In addition to polymer screening, this initial screening effort also involved [redacted]

(b) (4)

[redacted]

Figure 9. [redacted]

This initial screening program laid the foundation for carrying the formulation effort [redacted] screened rigorously for physical, chemical, weatherability and life cycle cost performance.

B. Phase I Formulation Qualification Results

The testing regime for this Phase I effort modeled the coating requirements outlined in MIL-C-53039B (topcoat) and MIL-P-53030/53022 (primer). A subset of the physical characteristic, chemical resistance and weatherability tests outlined in these specifications were selected to establish a high degree of confidence in the proof-of-concept results for each of the coating candidates.

Test specimens were prepared in accordance with the specification requiremenst, and in most cases, a control standard (MIL-C-53039B Olive Drab and MIL-P-53022 both from Sherwin Williams), was tested side by side for comparison purposes.

Table 2. General Test Methods

Test	MIL-C-53039B or Description	Test Method
Specular Gloss	4.3.10	ASTM D523
VOC Content	4.3.7.1	ASTM D3960
DS-2 Resistance	4.3.23	NA
Solvent Resistance	MEK and Methylene Chloride rubs	ASTM D5402
Hardness	NA	ASTM D3363
Adhesion	NA	ASTM D3359
Recoat Adhesion	4.3.17	ASTM D3359
Flexibility	3.6.5 (1/4" mandrel used)	ASTM D1737
Water Resistance	4.3.18	ASTM D1308
Hydrocarbon Resist	4.3.19	ASTM D1308
Acid Resistance	4.3.20	NA
Chemical Agent Resist	4.3.24	NA
Oxygen Permeability*	NA	ASTM D3985
Water Vapor Perm.	NA	ASTM E96
Atlas Test Cell	NA	ASTM C868-77
QUV Testing	4.3.22	ASTM G26

**These tests are only run on primer candidates.*

As noted above, these preliminary tests were run on primer candidates and topcoat candidates. The following outlines the compositional properties of the two candidate systems.

Table 3. [redacted]

[redacted]

Table 4 [redacted]

[redacted]

Basic Physical Performance

Basic physical performance testing considered the baseline physical properties of the coating candidates such as adhesion, chemical, water and hydrocarbon resistance and specular gloss. All samples were sprayed on phosphate treated steel panels obtained from Q-panel, using High-pressure, Low-volume spray equipment at an approximate dry film thickness of 2 mil. Table 5 outlines test results

Table 5. Basic Physical Performance Results

Test	Test Description	MIL-C-53039B	MIL-P-53022/30	(b) (4)
Specular Gloss	Scattering effect at 60° incident angle	~0.7	11	[redacted]
VOC Content		3.5	2.8	
Solvent Resistance (200 Methyl Ethyl Ketone Rubs)	Solvent Resistance (200 Methyl Ethyl Ketone Rubs)	pass	pass	
Hardness		~3H	B	
Flexibility	¼" mandrel bend test	pass	fail	
Water Resistance	168 hr immersion	pass	pass	
Hydrocarbon Resistance	168 hr immersion in kerosene	pass	pass	
Acid Resistance	15 minute exposure to acetic acid solution	pass	marginal	
QUV Resistance	Color stability in UV/condensation chamber	pass	pass	

Adhesion and Intercoat Adhesion Testing

Dry adhesion testing was carried out using the cross-hatch method seven days after drying. Intercoat adhesion tests were run after approximately 2 days dry time (including 24 hours in the oven at 140°F). In accordance with the ASTM 4.3.17, an adhesion rank was assigned to each coating's performance as described in Table 6.

Table 6. Adhesion Testing via Cross-Hatch Method

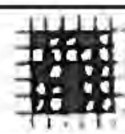
Description	Surface	ASTM
The edge of the cuts are completely smooth, none of the squares of the lattice is detached	None	5B
Detachment of small flakes of the coating at the intersections of the cuts. A cross cut area not significantly greater than 5% is affected		4B
The coating has flaked along the edges and/or at the intersections of the cuts. A cross cut area significantly greater than 5%, but not significantly greater than 15%, is affected		3B
The coating has flaked along the edges of the cuts partly or wholly in large ribbons, and/or it has flaked partly or wholly on different parts of the squares. A cross cut area significantly greater than 15%, but not significantly greater than 35%, is affected		2B
The coating has flaked along the edges of the cuts in large ribbons and/or some squares have detached partly or wholly. A cross cut area significantly greater than 35%, but not significantly greater than 65%, is affected		1B
Any degree of flaking that cannot even be classified by classification 4	-	0B

Table 7. Adhesion and Intercoat Adhesion Results

Test	MIL-C-53039B	MIL-P-53022/30	(b) (4) [redacted]
Adhesion	3B-5B	5B	
Intercoat Adhesion	3B-5B	NA	

(b) (4) [redacted]

(b) (4) [redacted]

(b) (4) [redacted] have been exposed to chemical warfare agent. This material is comprised of Sodium Hydroxide, Diethylenetriamine and Ethylene Glycol Monomethyl Ether and is very aggressive to coated surfaces. MIL-C-53039B requires 30 minute exposure to the chemical with no change in color and loss of no more than two units of pencil hardness immediately following removal of the DS-2 solution.

(b) (4) [redacted]

Table 8. DS-2 Resistance Results

Test	MIL-C-53039B	MIL-P-53022/30	(b) (4) [redacted]
DS-2 Resistance (hardness)	pass	H/HB	

Accelerated Weathering / Atlas Test (Cold Wall Effect)

In addition to QUV testing to determine the effect of sunlight on the color stability of the coating, Atlas Test Cell was run on primer candidates to determine their ability to tolerate this especially aggressive exposure. This testing is carried out at the internal cell temperature of 1400F, and provides a means to quickly identify the performance properties relating to substrate adhesion which is the primary means for corrosion onset. In addition, water vapor and oxygen gas permeability are presently being carried out to determine the susceptibility of coated substrates to corrosion by means of oxidation due to the ability of these gasses to reach the substrate. The results of these tests will be reported in an appendix to this Final Report.

Table 9. Corrosion Resistance Testing

Test	MIL-C-53039B	MIL-P-53022/30	(b) (4)
Oxygen Permeability	over-range	in testing	[redacted]
Water Vapor Perm.	over-range	in testing	
Atlas Test Cell	NA	pass	

Chemical Agent Resistance Testing

In order to evaluate chemical agent resistance performance, an ASTM F-739 (chemical agent permeation) cell was modified (Figure 10) to carry out chemical agent testing using the surrogate for HD Mustard, Chloroethylethyl sulfide (CEES or half-Mustard). These tests were carried out in accordance with the chemical agent test requirements outlined in MIL-DTL-64159.

CHEMICAL AGENT TEST APARATUS

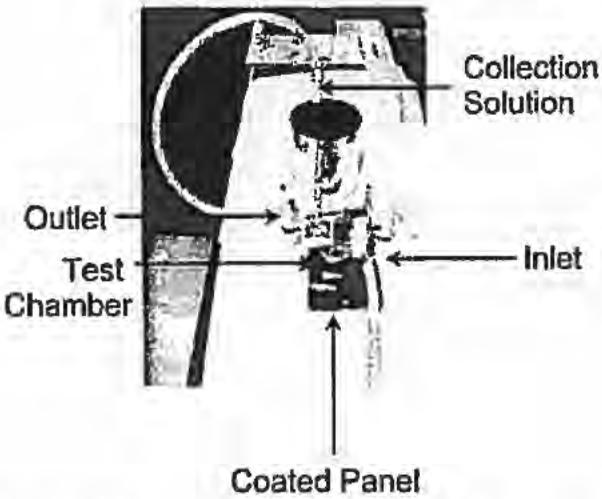


Figure 10. Modified F-739 Test Cell for Chemical Agent Testing

This test cell is clamped to a contaminated and isopropanol treated coating surface and will force inert air (argon) into the test cell and over the coating surface. An outlet port, which outgases into an acetonitrile collection beaker will provide a means to collect any contaminant contained in the airstream. The acetonitrile solutions were tested using gas chromatography after completion of the 22 hour test run. This testing effort has laid the foundation for the live chemical agent testing, which will take place in the Czech Republic in collaboration with U.S. Military observers in January, 2004.

(b) (4)

[redacted]

Table 10. Chemical Agent Surrogate Test Results

Sample	GC Peak Area (~3.5 mins)	Est. Mass Correlation
MIL-C-53039	2.0×10^7	2.4μg
[redacted]		

As mentioned above, live chemical warfare agent testing will be carried out in the Vyshkov Test Facility, Czech Republic during January 5-11, 2004. Coating candidates will be tested for adsorption of live Soman (GD) and Mustard (HD) agents using both MIL-C-53039 and NATO testing protocols for chemical agent resistance. These test results will be reported in an appendix to this Final Report.

C. Life Cycle Cost

A few decades ago the protective coating of military transport equipment could be accomplished for \$10 to \$20 per square meter of surface area. In recent years, the tremendous increase in the impact of regulations pertaining to painting have substantially increased the cost This is further increased since the performance expectations are also expanding due to demands for survivability, force protection, lifetime, and durability under severe exposure conditions.

The focus for prudent expenditures must shift to achieving long-term effectiveness for the dollars spent which dictates a fundamental understanding of the life-cycle cost impacts return on the large investment.

Development of advanced methodology for addressing these demands must deal with the personnel exposures, containment of solvent vapors, disposal of residual materials, and conformance with environmental regulations. There are relevant cost contributions associated with changing regulations that deal with removal and handling of hazardous debris during painting operations. Significant cost implications can be achieved by the use of environmentally compliant materials and especially with low volatile-organic-compound (VOC) coating systems.

This analysis focuses on the relative cost/benefit of the durability of various paint systems based on performance data and relative costs of material and application This analysis addresses life-cycle versus initial-cost analysis for various painting scenarios. The results of this study are in the form of a spreadsheet program, which is useful in comparing the various painting options based on a life-cycle cost analysis.

(b) (4)

[redacted]

Successful minimization of life-cycle costs for maintenance requires: (1) accurate data concerning cost and material performance and (2) user-friendly tools for assessing the relative cost impacts of various maintenance options. Models that present the relative cost of available maintenance strategies must be developed. These models must be constructed using sound engineering, planning, and economic principles, and the intended audience must be able to easily understand and use the model in real-world decision-making processes.

The life cycle cost evaluation is based on a model which considers costs elements in terms of the cost incursion flow, namely, material cost (procurement), QA/QC Cost (inventory and preparation), Application Cost and Performance Cost (field performance and maintenance). Figure 11 illustrates this life cycle cost model.

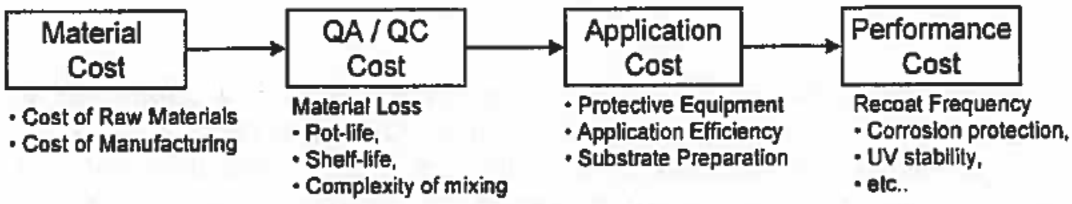


Figure 11. Life Cycle Process Flow

Table 11 outlines the results of the life cycle cost analysis. In the Phase I effort, Material Cost has been defined and some information as to QA/QC cost could be estimated for comparison with existing primer and topcoat systems. These parameters indicate that the new systems are within the order-of-magnitude cost realm of the existing coatings. [redacted] (b) (4)

Table 11. Life Cycle Cost Findings

Parameter	MIL-C-53039B	WB-CARC*
Material Cost	$36/gallon	$52/gallon
$ Cost/sq.ft.	0.08	0.01
Material Loss (waste disposal)	4 hours (less if temperature above 78F)	4-6 hrs after mixing (3 component system)
Shelf-life	approx. 1 year	approx. 1 year
Complexity of Mixing	single component	three component
$ Cost of Application	0.4	0.4
Protective Equipment (VOC)	3.6 lb/gal; contains isocyanates	1.8 lb/gal; contains isocyanates
Performance Cost		
In $ per year of service life	0.17	0.14
Surcharge for Environmental Consequence	TBD: California has lead. Penalties are stiff	TBD: This formulation reduces by 1/2
Reserve for Product Liability Exposure ***	TBD	TBD
Added Value of ennhanced CARC (troop survivability)	TBD	TBD

(b) (4) [redacted]

(b) (4) [redacted]

D. (b) (4) [redacted]

(b) (4) [redacted]

(b) (4) [redacted]

In terms of environmental hazard, the VOC solvents are dangerous to the environment because of their potential to react in the presence of light and form ozone in the lower atmosphere. This is a causative factor in the creation of Smog. [redacted] (b) (4)

[redacted] (b) (4)

Figure 12. [redacted] (b) (4)

Note that acetone, which will be produced in the future SILON system, is considered by EPA to have "negligent" photochemical oxidation potential and is a VOC-exempt solvent.

VI. Conclusions and Next Steps

1. The Isotron scientists have developed a new generation of CARC primer and topcoat coatings that provide the environmentally benign, low toxicity, feature that are sought by the Marine Corps.
2. These new coating compositions can be characterized as single pack and applicator friendly compositions.
3. These coatings utilize an advanced pigmentation strategy that results in CARC performance that is unprecedented.
4. The chemical agent resistance is significantly improved. This has been determined using simulants. During the next month this will be confirmed using live agent testing in the Czech Republic.
5. One of the topcoat formulations incorporates a self-priming feature. This will permit a one coat direct to metal option for the next generation of CARC coating.
6. The technical approach to this coating composition lays the foundation for a self-decontamination composition.
7. The primer composition has promise to extend the performance lifetime over the existing material while providing the above mentioned environmental and safety features.
8. The life cycle cost model that is emerging as a result of this development testifies to the overall strategic benefits afforded by this technology.
9. The Option phase work will provide the opportunity to gain additional insight into the health and safety, the shelf life, the anticorrosive feature, and the chemical agent resistance.

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